liquid crystal cell. It is respectfully submitted that the claims encompass either direction of rotation. The particular direction of rotation is not relevant. As long as one uses a consistent reference direction for all measurements, either clockwise or counter-clockwise, the results would be the same.

The Office Action alleges that claim 3 is inconsistent with the elected embodiment, noting that the specification discloses an output polarizer angle of 30 degrees, whereas claim 3 encompasses an output polarizer angle of minus 30 degrees. In response to the question presented in the Office Action, the angle values presented in the specification represent absolute values. Thus, the polarizer angle of the elected embodiment can be plus or minus 30 degrees. It is respectfully submitted that claim 3 is consistent with the elected embodiment.

In summary, it is respectfully submitted that, when read in light of the specification, the meanings of the terms presented in the claims are readily understood by a person of ordinary skill in the art. Reconsideration and withdrawal of the rejection is respectfully requested.

Respectfully submitted,

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OPTICS SOURCE BOOK

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Cover: Infrared thermogram showing thermal effluent entering a slow-moving stream with flow from left to right. (*Barnes Engineering Co.*)

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the vibrations is completely predictable. For certain disturbances, such as the transverse acoustic wave produced when a steel bar is struck, the polarization is complete. Electromagnetic radiation is normally unpolarized if it is generated by atomic processes. Thus ultraviolet, visible, and infrared radiations produced by heated bodies or electrical discharges are generally unpolarized. Radiation generated by vacuum-tube oscillators or transistor oscillators is always polarized. The probability waves (matter waves) associated with atomic or nuclear particles are generally unpolarized. *SEE ELECTROMAGNETIC RADIATION.*

Some of the different types of polarization, as well as the technique of producing polarization in an unpolarized wave, are described in another article. The electric vector can lie in a plane or it can follow a path whose projection at right angles to the direction of propagation is a circle or an ellipse. The same types of polarization can be produced in any transverse wave. *SEE POLARIZED LIGHT.*

Electromagnetic radiation is difficult to polarize in certain spectral regions, and few techniques exist for analysis. This is true in the ultraviolet below 190 nanometers. No dichroic polarizers have been found for this region, and transparent birefringent materials from which Nicol or Wollaston polarizing prisms could be made do not seem to exist. Polarization by reflection is possible, but very little work has been done with this technique. In the infrared region from the end of the visible spectrum to approximately 2 micrometers, sheet polarizers exist. To around 4 μm, polarizing prisms can be made. From 4 to 80 μm, reflection from a single plate or transmission through a pile of transparent plates is the common procedure. All these techniques produce linear polarization. Elliptical or circular polarization is more difficult to achieve.

X-ray photons, electrons, neutrons, and other particles can be polarized most easily by scattering.

POLARIZED LIGHT

BRUCE H. BILLINGS

Light which has its electric vector oriented in a predictable fashion with respect to the propagation direction. In unpolarized light, the vector is oriented in a random, unpredictable fashion. Even in short time intervals, it appears to be oriented in all directions with equal probability. Most light sources seem to be partially polarized so that some fraction of the light is polarized and the remainder unpolarized. It is actually more difficult to produce a completely unpolarized beam of light than one which is completely polarized.

The polarization of light differs from its other properties in that human sense organs are essentially unable to detect the presence of polarization. The Polaroid Corp. with its polarizing sunglasses and camera filters has made millions of people conscious of phenomena associated with polarization. Light from a rainbow is completely linearly polarized; that is, the electric vector lies in a plane. The possessor of polarizing sunglasses discovers that with such glasses, the light from a section of the rainbow is extinguished.

According to all available theoretical and experimental evidence, it is the electric vector rather than the magnetic vector of a light wave that is responsible for all the effects of polarization and other observed phenomena associated with light. Therefore, the electric vector of a light wave, for all practical purposes, can be identified as the light vector. *SEE CRYSTAL OPTICS; ELECTROMAGNETIC RADIATION; LIGHT; POLARIZATION OF WAVES.*

One of the simplest ways of producing linearly polarized light is by reflection from a dielectric surface. At a particular angle of incidence, the reflectivity for light whose electric vector is in the plane of incidence becomes zero. The reflected light is thus linearly polarized at right angles to the plane of incidence. This fact was discovered by E. Malus in 1808. Brewster's law shows that at the polarizing angle the refracted ray makes an angle of 90° with the reflected ray. By combining this relationship with Snell's law of refraction, it is found that Eq. (1) holds, where i is

$$\tan i = n \tag{1}$$

the angle of incidence and n is the refractive index. This provides a simple way of measuring refractive indices. *SEE REFRACTION OF WAVES.*

Law of Malus. If linearly polarized light is incident on a dielectric surface at Brewster's angle (the polarizing angle), then the reflectivity of the surface will depend on the angle between the incident electric vector and the plane of incidence. When the vector is in the plane of incidence, the reflectivity will be at a maximum. To compute the complete relationship, the incident light vector **A** is broken into components, one vibrating in the plane of incidence and one at right angles to the plane, as in Eqs. (2) and (3), where θ is the angle between the light vector and a

$$A_{\parallel} = A \sin \theta \qquad (2) \qquad\qquad A_{\perp} = A \cos \theta \qquad (3)$$

plane perpendicular to the plane of incidence. Since the component in the plane of incidence is not reflected, the reflected ray can be written as Eq. (4), where r is the reflectivity at Brewster's angle. The intensity is given by Eq. (5). This is the mathematical statement of the law of Malus.

$$B = Ar \cos \theta \qquad (4) \qquad\qquad I = B^2 = A^2 r^2 \cos^2 \theta \qquad (5)$$

* **Linear polarizing devices.** The angle θ can be considered as the angle between the transmitting axes of a pair of linear polarizers. When the polarizers are parallel, they are transparent. When they are crossed, the combination is opaque. The first polarizers were glass plates inclined so that the incident light was at Brewster's angle. Such polarizers are quite inefficient since only a small percentage of the incident light is reflected as polarized light. More efficient polarizers can be constructed.

Dichroic crystals. Certain natural materials absorb linearly polarized light of one vibration direction much more strongly than light vibrating at right angles. Such materials are termed dichroic. For a description of them SEE DICHROISM.

Tourmaline is one of the best-known dichroic crystals, and tourmaline plates were used as polarizers for many years. A pair was usually mounted in what were known as tourmaline tongs.

Birefringent crystals. Other natural materials exist in which the velocity of light depends on the vibration direction. These materials are called birefringent. The simplest of these structures are crystals in which there is one direction of propagation for which the light velocity is independent of its state of polarization. These are termed uniaxial crystals, and the propagation direction mentioned is called the optic axis. For all other propagation directions, the electric vector can be split into two components, one lying in a plane containing the optic axis and the other at right angles. The light velocity or refractive index for these two waves is different. SEE BIREFRINGENCE.

One of the best-known of these birefringent crystals is transparent calcite (Iceland spar), and a series of polarizers have been made from this substance. W. Nicol (1829) invented the Nicol prism, which is made of two pieces of calcite cemented together as in **Fig. 1**. The cement is Canada balsam, in which the wave velocity is intermediate between the velocity in calcite for the fast and the slow ray. The angle at which the light strikes the boundary is such that for one ray the angle of incidence is greater than the critical angle for total reflection. Thus the rhomb is transparent for only one polarization direction.

Canada balsam is not completely transparent in the ultraviolet at wavelengths shorter than 400 nanometers. Furthermore, large pieces of calcite material are exceedingly rare. A series of polarizers has been made using quartz, which is transparent in the ultraviolet and which is more commonly available in large pieces. Because of the small difference between the refractive indices of quartz and Canada balsam, a Nicol prism of quartz would be tremendously long for a given linear aperture.

A different type of polarizer, made of quartz, was invented by W. H. Wollaston and is shown in **Fig. 2**. Here the vibration directions are different in the two pieces so that the two rays are

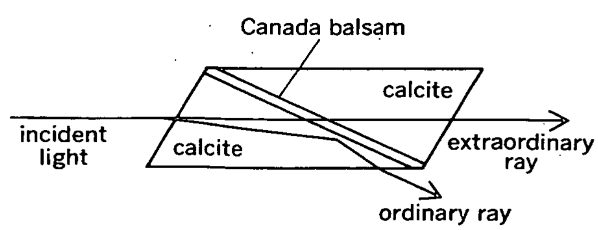

Fig. 1. Nicol prism. The ray for which Snell's law holds is called the ordinary ray.